Appendix B. Dissolved Oxygen Modeling

1.0 North Fork Sugar Creek

The 1998 303(d) list included Organic Enrichment/D.O. as a major cause of impairment for the North Fork, Little Sugar Creek, and Sugar Creek (Headwaters to Middle Fork). Water quality data collected during 1998-99 indicates that dissolved oxygen (D.O.) is not a cause of impairment in those segments. A discharger to the North Fork (Gerber Poultry) is planning an expansion, therefore D.O. modeling was performed to assess the possible impact of excessive nutrient loads on water quality at 7Q10 flows.   The Qual2E dissolved oxygen model was used to simulate instream dissolved oxygen and nutrients under various alternatives. One of the scenarios includes a proposed wastewater treatment plant that would discharge to the North Fork Sugar Creek upstream of the point where Gerber Poultry discharges (through a tributary) to the North Fork.   More details about the D.O. modeling are given below.

Model Overview

The Enhanced Stream Water Quality Model (QUAL2E) is a comprehensive and versatile water quality model, intended to be used as a water quality planning tool. Technical support for this model is provided by U.S. EPA.   QUAL2E can simulate up to 15 water quality constituents, and is designed for well mixed streams under steady state conditions (i.e. the simulations are limited to periods when the streamflow and the input waste loads are essentially constant).   The stream is divided into reaches having fairly uniform hydraulic (velocity, depth, width) characteristics. Each reach is divided into computational elements (think of them as a series of connected bathtubs, whose width and depth you define for each reach based on field measurements).   Each element can gain or lose mass by transport processes, wastewater discharges, or withdrawals. Mass can also be gained or lost in each element through biological transformations (uptake and release) or settling.   Among the major factors affecting dissolved oxygen is reaeration, which is the entrainment of oxygen in/out of the water column from turbulence (riffles, falls, etc.) as well as diffusion across the air/water boundary (USEPA, 1985).   QUAL2E was used to simulate D.O., BOD5, phosphorus, and the nitrogen series (organic N, ammonia-N, nitrite-N, and nitrate-N) in the North Fork Sugar Creek.

Model Calibration and Validation

The model was calibrated using water quality and hydraulic data collected during 1993 and 1998 Ohio EPA surveys of the North Fork.   The stream slope was estimated from USGS topographic maps. The reaeration rates for the North Fork were determined from 5 predictive equations selected on the basis of streamflow and reach slope. These equations were selected by Ohio EPA among 18 equations as the ones showing the smallest relative errors relative to field measurements of reaeration rates performed in Ohio streams (Skalsky & Fischer, 1984). The rates vary with velocity and depth (therefore are flow dependent). The equations used for the North Fork were Tsivoglou-Neal (from RM 6.1 to 2.0) and Parkhurst-Pomeroy (from RM 2.0 to the mouth).   Due to its pronounced slope downstream of Kidron, the North Fork has high reaeration rates from RM 6.1 to RM 4.6 , which help explain the high assimilative capacity of this creek.   The steep slope of the North Fork is evident in Figure 1. The slope decreases between RM 2.0 and the mouth, and the

lower reaeration rate in the lower reach increases the likelihood of D.O. violations if the load of nutrients is excessive. QUAL2E helps determine if D.O. problems will arise with increases in effluent flow.

Figure 1. Change in Elevation with River Mile for North Fork Sugar Creek

N Fork Sugar Ck: Elevation vs RM
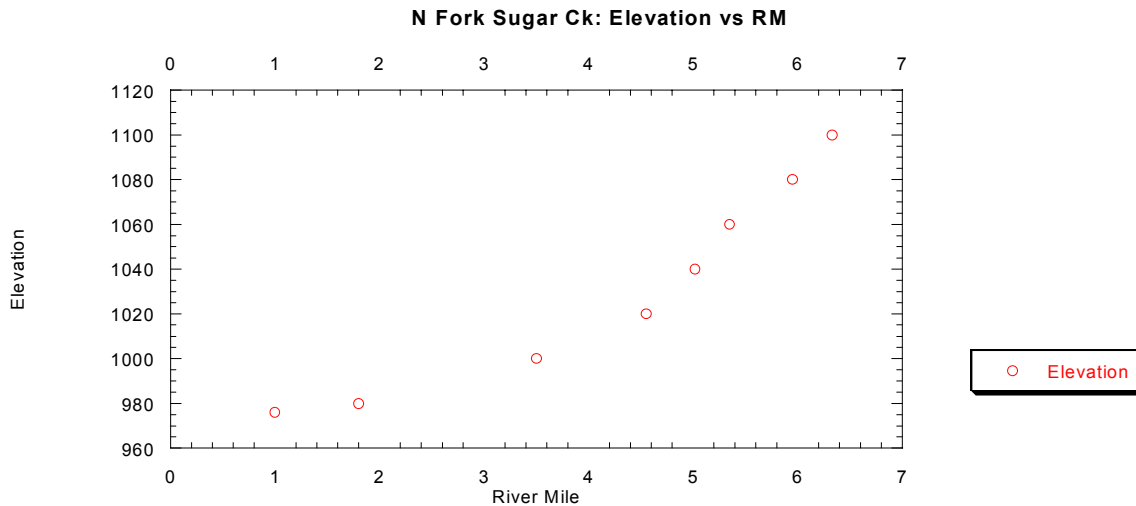
Decay rates for CBOD, NH3-N, NO3-N and phosphorus were determined by plotting observed water quality concentration vs. time of travel (in days), and adjusting the decay rate as necessary to account for settling and dilution from incremental flows observed during the surveys. Figure 2 illustrates the change in concentration of total phosphorus in the North Fork between RM 5.4 and 1.35 (Zuercher Rd to West Lebanon Rd), and the exponential decay curve that was fit to the data. The data is for the July 7, 1998 Ohio EPA survey.

Figure 2. Total Phosphorus Concentration Observed in the North Fork from RM 5.4-1.35

Total Phosphorus (mg/l) in N Fork Sugar Ck
RM 5.4 to 1.35   (July 7, 1998)
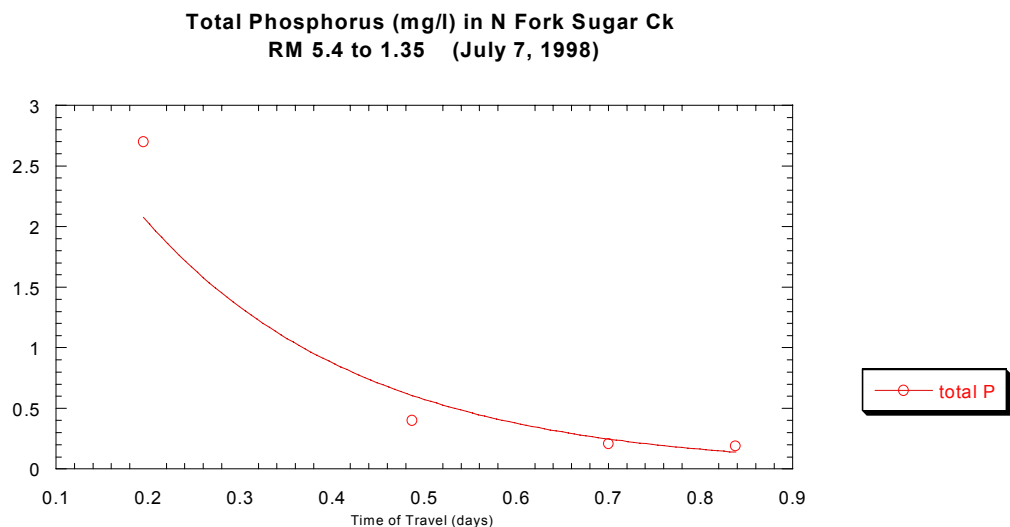
Time of travel and cross sectional area measurements were made from in the North Fork from river mile 6.1 to 1.3 to determine the relationship between stream flow, velocity and depth for each reach. The time of travel studies were done by injecting a fluorescent dye (Rhodamine WT) at an upstream site, and collecting stream samples at periodic intervals at downstream sites. The dye concentrations in water were measured in the field with a fluorometer to determine the time when the dye passed through each sampling station.

The equations that describe the relationships between streamflow, velocity and depth are shown below:

$$\text{Velocity} = cQ^d$$

$$\text{Depth} = aQ^b$$

where

Q = streamflow
a, c = coefficients for depth and velocity
b, d = exponents for depth and velocity

The coefficients and exponents that describe how velocity and depth change with streamflow are shown in Table 1 for each reach in the North Fork Sugar Creek.

Table 1. Hydraulic Coefficients and Exponents for the North Fork Sugar Creek

Reach	Reach Description	River Mile Range	Depth		Velocity	
			a	b	c	d
1	N Fork upstream Gerber trib.	6.1- 5.8	.44	.20	.22	.44
2	Gerber tributary	0.8 - 0.0	.74	.60	.44	.40
3	N Fork - Zuercher Rd	5.8 - 4.6	.44	.20	.22	.44
4	N Fork - Western Rd	4.6 - 3.8	.42	.32	.18	.44
5	N Fork - Rt. 241	3.8 - 2.0	.42	.32	.275	.40
6	N Fork - W. Lebanon Rd	2.0 - 1.3	.25	.52	.13	.40
7	N Fork - down to mouth	1.3 - 0.0	.25	.52	.13	.40

The velocity and depth coefficients were determined by plotting the average reach velocity (obtained from time of travel measurements) and depth versus streamflow and determining the coefficient and exponent that best fit the observed data. The velocity vs. streamflow data for one of the reaches in the North Fork is shown in Figure 3.

Figure 3. Relationship between Streamflow and Velocity for the North Fork up to RM 3.8

Velocity/Flow relation for N Fork Sugar Ck: RM 6.1- 3.8
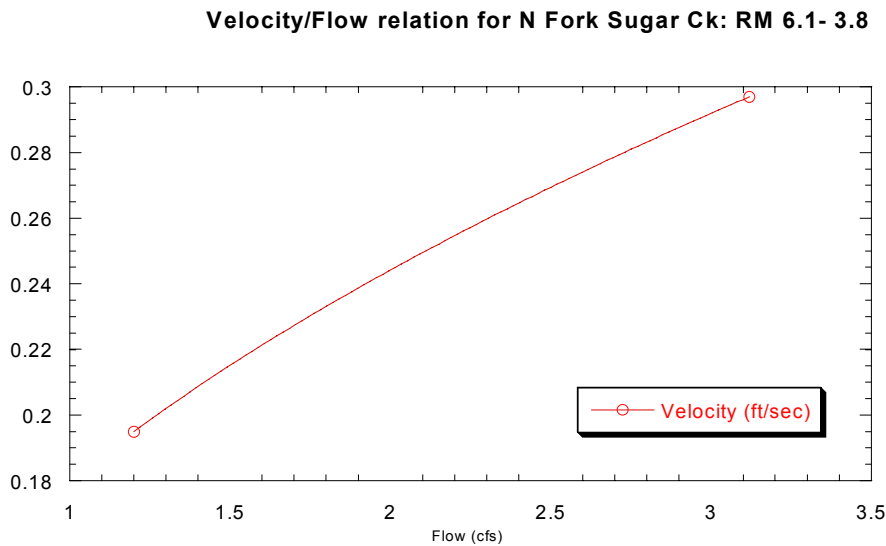
A summary of the most relevant reaction rates used in the Qual2E model are shown in Table 2.

Table 2. Summary of Important Rates (at 20ºC) Used in the North Fork Qual2E model

Reach	River Mile Range	CBOD decay	Sediment oxygen demand	Ammonia oxidation	Organic N Hydrolysis	Nitrite oxidation
		(day^{-1})	$(g/ft^2/day)$	(day^{-1})	(day^{-1})	(day^{-1})
1	6.1- 5.8	0.8	0	1.35	0.65	1.0
2	0.8 - 0.0	2.0	0	1.35	0.65	1.0
3	5.8 - 4.6	0.8	0	1.35	0.65	1.0
4	4.6 - 3.8	0.8	0	1.35	0.65	1.0
5	3.8 - 2.0	0.8	0	1.35	0.65	1.0
6	2.0 - 1.3	0.8	0	1.35	0.65	1.0
7	1.3 - 0.0	0.8	0.05	1.35	0.65	1.0

Due to decreased slope as the North Fork gets close to the confluence with the mainstem, it was assumed that there would be some settling of solids, thus increasing sediment oxygen demand (SOD). A moderate rate of SOD (0.05 grams/ft2/day) was assigned downstream of river mile 1.3 to assess possible impact on water column dissolved oxygen. The SOD rate was based on sediment oxygen demand studies performed in Illinois (Butts et.al., 1978).

The data collected during 1998-99 indicated that dissolved oxygen (D.O.) water quality standard violations were very infrequent in the North Fork during the sampled period. Only one out of 14 instantaneous D.O. samples showed a value below 4 mg/l, which is the minimum concentration allowed for WWH streams. This is an improvement over conditions found in 1993, when many D.O. standard violations were recorded. However, the largest point source discharger to the North Fork (Gerber Poultry) has requested Ohio EPA's approval for an expansion. The plant could increase its design flow up to 0.8 MGD over the next five years. The discharger is aware of the recommendations given in this TMDL report. In addition, the effluent from Gerber Poultry will interact with the discharge of a proposed wastewater treatment plant for the community of Kidron.

The calibrated QUAL2E D.O. model was validated by using data from a survey of the North Fork performed by URS Consultants during the summer of 1998. Ohio EPA and URS collaborated in the validation of the model. The validated model is being used to simulate water quality in the North Fork to determine the effluent limits to maintain applicable D.O. WQS.
(URS Greiner, 1998)

2.0 Additional D.O. Modeling in Sugar Creek basin

Sugar Creek near Brewster
The Sugar Creek segment downstream of the Middle Fork (downstream of Brewster) and upstream of the South Fork was not listed in the 1998 303(d) list. However, this segment has 2 dischargers in Brewster (Brewster Dairy and the Brewster WWTP) that contribute a significant nutrient load. The existing phosphorus loads from these and other dischargers are shown in table 15 of the TMDL report. Dissolved oxygen modeling had been done previously for this reach, and the existing effluent limits were based on that modeling. The modeling was repeated using more current upstream water quality data (collected during the 1998 surveys) to verify if the existing permit limits are adequate to meet the D.O. water quality standards. The simulation showed that no D.O. problems are expected downstream of Brewster at summer 7Q10 flows. A slight reduction in effluent ammonia was recommended (shown in section 6.1.4 of the TMDL report) in order to meet instream ammonia WQS. The phosphorus load reductions recommended basinwide should result in future D.O. improvement in this reach, as algal impacts decrease concurrently with phosphorus loads.

South Fork Sugar Creek near downstream Sugarcreek WWTP
This segment of the South Fork is located immediately downstream of a listed segment (described in section 2.3.7 of the TMDL report) that receives the effluent of American Whey. It is interactive with the Sugarcreek WWTP effluent, which comes into the South Fork within 0.1 mile of the American Whey tributary. Their relative location within the watershed can be seen in figure 3 of the report (Sugar Creek schematic). Previously existing dissolved oxygen simulations were repeated under 7Q10 critical flows, using more recent (1998) upstream water quality data. The simulation results show that the effluent limits recommended in section 6.1.7 for American Whey and the Sugar Creek WWTP are adequate to maintain the average dissolved oxygen standard. This reach was reclassified as Modified Warmwater habitat, which has a D.O. WQS of 4 mg/l. The predicted instream D.O. is above 5.

References

Butts T.A. & R.L. Evans, 1978. Sediment Oxygen Demand Studies of Selected Northeastern Illinois Streams, Illinois State Water Survey, Urbana, Illinois, ISWS/CIR-129/78.

Skalsky D.S.& L.D. Fischer, 1984. Predicting the Reaeration Coefficient for Ohio Streams, Ohio Environmental Protection Agency.

URS Greiner, 1998. Simulation of the Effects of Increased Discharge from the Gerber Poultry Facility in Kidron, Ohio on North Fork Sugar Creek.

USEPA, 1985. Computer Program Documentation for the enhanced Stream Water Quality Model QUAL2E, U.S. Environmental Protection Agency, EPA/600/3-85/065.